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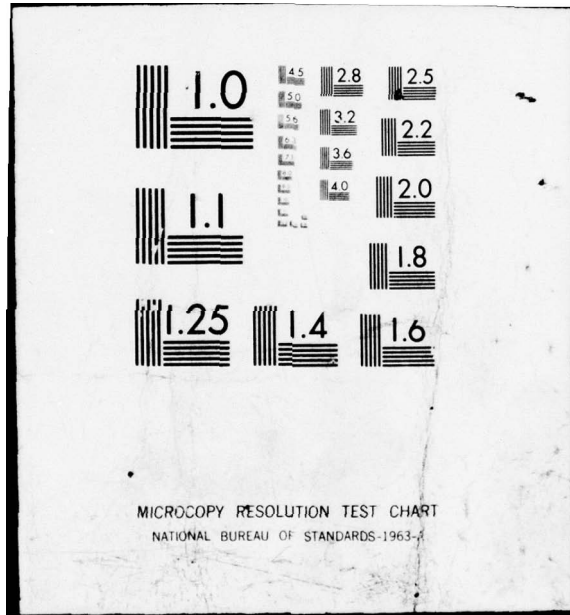
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A further critical factor is depth-of-flow, because greater depths of flow permit an ice cover to form but allow flow to continue underneath, while smaller depths of flow freeze completely leading to flow blockage. The report summarizes several processes for ice formation and blockage in culverts, ditches, and subsurface drains. Solutions to ice blockage problems involve ice prevention and ice control, usually the latter. In some cases, culverts can be closed, leading to intentional ponding and storage of ice. Alternatively, flow can be maintained in culverts by heating them electrically, with steam, or with oil-burner heaters. Ditches can also be heated, but it is usually more effective to widen them to provide more storage space for ice, or to install insulating covers. Subsurface drain outlets can be heated, protected with insulating covers, or partially blocked to prevent cold air entry. Ground seepage that forms ice is successfully controlled using ice fences. Design changes, such as more and larger drainage structures, staggered culverts, and channel modifications, are discussed. Four CRREL publications are cited as sources of additional information.

PREFACE

This report was prepared by Kevin L. Carey, Research Civil Engineer,
of the Applied Research Branch, Experimental Engineering Division, U.S.
Army Cold Regions Research and Engineering Laboratory.

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SOLVING PROBLEMS OF ICE-BLOCKED DRAINAGE FACILITIES

by

Kevin L. Carey

INTRODUCTION

Freezing winter weather often brings headaches for maintenance forces responsible for streets and highways, railroads, airfields, and other public works. And a good share of these headaches arises from drainage facilities that become blocked or restricted by ice. Many problems of this sort could be avoided by proper drainage design, and maintenance personnel often can make valuable suggestions to designers, based on their experiences with winter operations. But the winter problems remain for existing facilities, and it is up to maintenance personnel to keep these facilities operating.

Many approaches and solutions to the problems of ice-blocked drainage have been arrived at by local forces in their own areas. Very likely there are some that we don't know about at the Cold Regions Research and Engineering Laboratory. But the purpose of this publication is to acquaint you with some solutions you may not be familiar with, or to give you some additional ideas in connection with solutions you may already know about, all based on our experiences in the world's cold regions with a wide variety of engineering works operating under many types of winter conditions.

TYPES OF PROBLEMS

Most problems with ice-blocked drainage facilities are centered on culverts, ditches, and subsurface drains. Additional problem spots are inlets and outlets, scupper drains and downspouts, small bridge openings, and flow-control structures, to name a few. In simplest terms, ice forms and grows in places that should be open and clear for flow. The result is that water cannot pass freely through the drainage facilities, and in cases of complete blockage, water may become ponded in areas or diverted to areas that were meant to be kept drained. With this happening at freezing or lower temperatures, water and ice can interfere with and become a hazard in the operation of the roadway, airfield, or whatever facilities the drainage is intended to serve. Other possible results are increases in water levels in streams and channels, raised water tables, saturated fills and embankments, washouts, etc.

Culverts

Ice formation inside a culvert reduces its cross section and its capacity to carry flow. Depending on slope, flow rate, inlet and outlet

conditions, etc., ice may build up uniformly throughout the length of a culvert, or it may form primarily at the entrance or the exit of the culvert. In some cases the culvert becomes filled by ice buildup that begins in the upstream or downstream channels and slowly grows toward the culvert. This is especially true in far northern localities, where a form of ice buildup known as "icing" spreads into culverts and often fills them completely (Figure 1).

Ditches

Ice blockage in ditches can lead to ponding and overflow. Ice can form in ditch bottoms and progressively build up to higher elevations (Figure 2), or it may enter from the side of the ditch as a result of freezing backslope seepage (Figure 3). Debris or heavy vegetation in a ditch that doesn't bother the flow in warm weather can become places of ice buildup in winter. Depending on how severe the climate is, wind-blown or fallen snow that fills a ditch can contribute to troublesome ice buildup. Normally snow acts as good insulation, so that water can seep or flow through snow at the base of the ditch without freezing. But then if the water reaches a point in the ditch which is snow-free, ice formation will occur rapidly and may form a dam to the ditch flow.

Subsurface Drains

Facilities for subsurface drainage are normally designed so that they don't get direct inflow from surface water. Instead, these facilities are intended to drain subsurface seepage or groundwater. But two ways exist in which ice blockage can occur. First, even though subdrains are supposed to be placed below frost depths, it may still happen that unusually deep frost penetration will reach the level of the drains and freeze the water inside them. If this happens in only part of the drainage system (for example, under an area that is kept free of snow, allowing deeper frost penetration), then seepage water will be backed up in the drainage system upstream from the points of ice blockage. This can cause things such as ground saturation and earth slumps or slides. The second and probably more common problem is to have ice blockage at the outlets of a subsurface drainage system, where the drainage water first encounters low air temperatures. When this happens, the entire system can become backed-up with water.

ICE-BLOCKAGE PROCESSES

The key factor in the formation of ice is heat-loss from the water. And heat-loss is mainly controlled by the exposure of the water to the atmosphere, and by the air temperature. It's obvious that the colder the air, the greater the heat-loss, and the greater the rate of ice formation. But the matter of exposure needs some explanation. Water loses

heat to air through three different physical processes (radiation, convection and conduction). Exposure really has to do with whether or not there are any barriers that stand in the way of heat-loss through any or all of these processes.

For example, a small stream in flat, open country, with very low banks and only grassy vegetation, has a very high exposure for ice formation. First, nothing stands between the water and the sky, and so radiation of heat to the sky is unrestricted. Second, the stream is open to the sweep of the wind, and so convection in the air can be effective in taking away the heat lost by the water. And third, in this open terrain, the air near the stream is probably just about as cold as anywhere else, so conduction of heat to the air is high. In contrast, picture a small stream in hilly or mountainous country, with high banks and very dense forest vegetation that overhangs the stream. Here the exposure for ice formation is very low. The overhanging vegetation shields much of the stream from the sky, so that heat-loss by radiation is low. The dense forest protects the stream from the wind, so that heat-loss through convection is low. And finally, the air temperature in the forest may be higher than in the open, so heat conduction would be less.

These two examples are given to help in visualizing what is involved in heat-loss from a water surface. But there is one other factor, in addition to heat-loss, that is important to consider in this subject of ice-blocked drainage facilities. That factor is depth of flow.

Depth of flow is important in relation to the thickness of ice that can be formed for any particular heat-loss condition. If the depth of flow is much larger than the thickness of ice that will grow, then ice-blockage usually won't occur. The problems of ice-blockage happen when the depth of flow is about the same as the thickness of ice that can form or smaller. Then the flow essentially freezes solid, reducing the cross-section of the facility (the culvert, drain, or ditch, etc.) and forcing the flow that follows to spread out on top of the already-formed ice and become frozen solid itself. This process can be repetitive, and in extreme cases a small flow can build up tremendous amounts of ice. (For example, if a flow as small as 8 gallons per minute is completely converted to ice, it will cover an acre of land to a depth greater than a foot in only a month's time.)

With the above paragraphs serving as general comments about ice-blockage, we can look in some detail at examples of particular ice-blockage processes. But even though we cover only a few examples here, you should be able to get the general ideas involved, and then begin to recognize the processes behind almost any sort of ice-blockage in drainage facilities.

Culverts

Probably the most common form of ice blockage in culverts is caused by the complete freezing, from surface to bottom, of the shallow flow at the bottom of the culvert. Both circular and pipe-arch metal culverts, and box-type concrete culverts, carry such small depths of flow in the winter that often the entire depth of flow is frozen. Then if flow continues from upstream, it must pass over the ice already formed, and it is liable to become frozen solid in the same way. In this way the ice builds upward, layer by layer, and restricts the size of the culvert cross-section. Now this is most likely to happen at one or both ends of the culvert, because here the exposure is greatest. In the middle of the culvert the exposure is less, and moreover the temperature is usually higher because the culvert is surrounded by the embankment soil which is usually much warmer than the air. So it is less common for complete freezing to happen in the middle. But if the culvert is large in diameter, and especially in windy locations, the slightly warmer conditions in the middle of the culvert are wiped out, and the ice-blockage can take place there just as well.

Another very common place for a culvert to become blocked by ice is at an end designed for free-fall of the flow leaving the culvert (Figure 4). In a case like this, the pipe extends out from the embankment above the toe of the slope. This means that the outside of the culvert is exposed to the air around its entire circumference, and so the flow along the bottom of the culvert is chilled not only at its top surface but also underneath as well. Quick freezing and blockage can result.

Other culvert situations that hasten ice problems are debris and splashing. Debris provides a good location for ice to form; it is cold and ice crystals in the flow can stick to it, closing off the small openings the water would usually flow through. Poor culvert shapes, poor inlet and outlet condition, and other causes can lead to splashing of the flow. When the splash falls on the cold surfaces of the culvert material, freezing is almost instantaneous and ice is built-up in thin layers. Given enough time, this action can restrict the flow and even block it entirely.

Ditches

Just as with culverts, the most common way that ditches become blocked by ice is the complete freezing from surface to bottom of shallow flows at the bottom of the ditch, followed by flow and freezing over and over again until ice builds up to the top of the ditch. A variation of this process occurs when the ditch is at the base of a cut slope, and seepage from the cut slope freezes as it runs down the slope to the ditch. Successive freezing of this sort builds up ice in the side and bottom of the ditch and may progress to the point of blocking it (Figure 5).

Snow can lead to ice blockage in ditches in a couple of ways. First, snow that fills the ditch either by drifting, plowing, or falling naturally will tend to block the ditch to water flow, especially if the snow is compacted. If the ditch is shallow or the depth of snow reasonably small, the snow that is saturated by the ditch flow can freeze quite easily. (With deeper ditches and thicker snow covers, the opposite result will happen. This is because the snow provides insulation to the unfrozen water at the bottom of the ditch.) Second, in the early spring when snow and snowbanks are melting during the day, this melt water runs to the ditches and when night comes the flow will freeze. Eventually as the spring progresses, daytime melting of snow exceeds the nighttime freezing of runoff. But early in the season, the freezing will be greater than the melting, so that the very time when drainage facilities are needed most, they are being built-up with ice.

Subsurface Drains

The outflow from subsurface drains, especially in the winter when there is little if any inflow, seldom is more than a trickle. So it is very easy for this outflow to become frozen at the points where it daylight, because the exposure is high and the depth of flow is small. Since the temperature within the subsurface drainage system is usually above freezing, water will continue to flow to the outlets and freeze there. With the eventual complete freezing of the outlets, water backs up, and the system becomes inoperative. The groundwater level rises, saturating the soils that were meant to be drained.

PROBLEM SOLUTIONS

The solutions to problems of ice-blocked drainage facilities fall into two categories: ice control and ice prevention. Actually a third category exists, the physical removal of ice after a facility has become blocked. But this approach, even though it is used a lot, is often not very satisfactory. It is more a case of reacting to the problems rather than solving them.

You probably won't be able to prevent the formation of ice in very many situations. Usually it takes changes in the design of drainage facilities to be able to prevent ice formation, but maintenance forces have to work with designs as they exist. So mainly you will be focusing your attention on ways of controlling ice buildup, that is, using techniques that may allow ice to form, but will slow down its formation or will maintain an unfrozen opening so that drainage flow can always pass through.

Remember that it is important in any approach to ice problems to keep culverts and ditches cleared of trash and debris. This basic requirement can remove the spots where ice blockage gets a start, and so can eliminate several ice problems right at the beginning.

In the following sections, we discuss problem solutions under the categories of culverts, ditches, etc. But that doesn't mean that the solutions can only be used for those facilities. If you see a solution here that you think is applicable in some other way, go ahead and use it. It may take some experimentation, but you may get excellent results.

Culverts

Where a problem exists because a culvert fills with ice, and if other conditions are right, it may be feasible to simply block off the culvert temporarily at the upstream end. This will work where the flow is very small, and where there is enough storage space upstream from the culvert to hold the resulting ice. Closures that have been used successfully are made of wood, innertubes, canvas, or sheet plastic. This technique keeps the culvert open so that it doesn't have to be thawed in the spring and it is ready for flow. But the closure has to be removed in the spring, and this may involve chopping or thawing ice.

Several techniques exist to apply heat to culverts, either to keep them from freezing or to thaw an opening through the ice blockage. The most successful of these involves the use of electric heating cables (Figure 6). These are usually of the mineral-insulated type with a copper or stainless steel sheath. Strung through the culvert in the fall and removed in the spring, these cables are turned on when needed. In some cases, they may be left on throughout the winter, but seldom is this necessary or efficient. In Alaska, some permanent installations have been made, with the heating cable enclosed in a small-diameter steel pipe mounted within the culvert one-fifth to one-quarter of the diameter up from the bottom and along one side of the culvert. The heating cables and voltages commonly used provide a maximum heat output of 40 to 50 watts per linear foot. However, good results can be gotten with electrical control devices that limit the output to lower values. For example, an output of only 10 watts per linear foot will melt a hole or tunnel in ice that reaches about 8 inches in diameter in 8 or 9 days.

Steam thawing is familiar to most maintenance people. The steam is usually generated in truck-mounted boilers, and applied through hoses connected to portable steam lances. But a great improvement in performance and convenience comes from the use of permanently installed thaw pipes within culverts. These thaw pipes are usually attached by clamps or hangers to the top of the culvert. Placing them at the culvert invert is less desirable owing to the chance of damage from falling ice or

waterborne debris. Pipe sizes used are 1/2, 3/4, and 1 in. in most cases, but sizes from 3/8 to 2 in. have also been used. The thaw pipe has a vertical riser at each end of the culvert, high enough to go above any ice or snow. The pipe is filled with an antifreeze solution, and the risers are capped except when steaming is done.

During steaming, a steam hose is attached to one of the risers, and a condensate-return hose is connected to the other riser. The antifreeze is collected through the return hose for re-use, and then the steam is cycled through the pipe. Anywhere from 30 min. to an hour is needed to make a hole about 4 in. in diameter, based on the output of ordinary small portable boilers. A thawed opening this size is usually enough to keep flow going through a culvert in the spring. Perforated thaw pipes don't do very well, because most of the thawing takes place only near the first few perforations, and the condensate can't be saved. Depending on the rate of ice buildup, steam thawing is done periodically throughout the winter. This will take care of mid-winter thaws and rains, but in particular the drainage facilities will be ready for runoff in the spring.

Fuel oil heaters, often called firepots, have been used in Alaska and Canada for years. They are inefficient and costly in both fuel and labor, but for one or two critical installations, they might be worth using in spite of their drawbacks. A firepot is made from an ordinary 55-gallon drum, equipped with a simple drip-feed or nozzle oil burner unit (Figure 7). Usually the drum is suspended from a tripod at the upstream end of a culvert, but it can be located any place you want to keep thawed. A gravity-feed fuel supply is placed nearby. If there is substantial flow, and the firepot goes out, it may become flooded and frozen in. And since the object is to prevent the freezing of the flow coming to the culvert, rather than melting ice once it has formed, usually the fire is kept burning continuously. Oil consumption averages 25 to 30 gal. per day. A large fuel supply at the site may not be practical because of possible theft. So it's necessary to refuel every day or two.

Ditches

If a critical problem spot exists in a ditch, it's possible to use electric heating cables, steam thaw pipes (or portable steam lances), or firepots as described above. But usually the ice blockages in ditches aren't confined to a few spots. Instead they exist over extended lengths of the ditches, and so some other remedy is called for.

One approach which involves some earthwork is to excavate ditches wider, or to excavate basins at appropriate points in the ditch system. This provides storage space for ice to form, without building up to levels that would cause ice to reach pavements or other areas that must

be kept clear. To size the storage space, you must have some idea of the flow rates that are involved. As a guide, a flow of 1 gal per minute when completely frozen, amounts to about 6500 cubic feet of ice in 30 days. Ordinarily, the spring thaw will take care of melting out the stored ice, but it may be necessary to thaw the culverts in the drainage system.

Another approach to solving ice blockage problems in ditches is to install temporary covers over the ditches. The covers provide dead air space as insulation so that the ditch flow is protected from freezing. Usually this would be done only at the points where the flow is most likely to freeze: shallow spots, flat points in the ditch slope, or parts of ditches that are unprotected by overhanging vegetation. The covers may be made of plywood, sheathing, corrugated metal or fiberglass, or any sort of panel material. Since the size of the ditch probably would be too wide for the cover pieces to span it, posts set in a grid-pattern would be needed for support. On top of the cover, insulation material can be added (for example, brush, sawdust, straw, or simply snow) to a thickness of a foot or two. Natural snowfall will add to the insulating properties of the cover.

Covers are expensive and time-consuming. They have to be installed in the fall and removed in the spring before meltwater runoff begins. But they can be very effective, and may be worth considering for critical problem spots.

Subsurface Drain Outlets

Frozen and blocked outlets for subsurface drains can be prevented in many cases by either heating or insulating against natural heat loss. Since the water temperature of the flow in a subsurface drain system is usually several degrees higher than surface flow in the winter, insulating the drain outlets has a good chance of working well. This is done in the same way as providing insulating covers for ditches. The cover begins at the outlet and goes downstream as far as necessary, to a point on the outlet channel where ice formation either won't happen or wouldn't matter if it did.

In relatively mild climates, another way of stopping heat loss from drain outlets is simply to hang canvas or burlap over the outlet. This cuts down the entry of cold air into the drain, and yet the flow can seep past the fabric without freezing.

Heating of drain outlets, either with electric heating cables or steam pipes, is done just the same as for culverts.

Ground Seepage

Sometimes maintenance personnel are faced with the problem of ground seepage, instead of concentrated flow, leading to troublesome ice buildups. The seepage may come from rock faces, cut slopes, natural slopes, or other types of places. Very big ice masses can form from small seepages, and the problem comes when these ice masses grow to the point where they encroach on the road or other area that has to be kept open.

These ice buildups can be held in place, away from the pavement, by temporary barriers. In Alaska, these are known as ice fences (Figure 8). They may be fabricated of snow fencing or wire fencing faced with plastic sheeting, tar paper, canvas, burlap, etc. These fences don't need to be very strong, because they hold back only a thin layer of water at any one time before it freezes. The temporary barrier is removed after melting begins in the spring.

Design Changes

Often the solution to an ice blockage problem can be brought about by changes in design. Of course this is out of the hands of personnel concerned with maintenance, but still they can be alert to a few possible design changes, and make recommendations for changes when they are called for.

Certainly the most obvious design solution for ice blockage problems is to provide more and larger drainage structures. Culverts with larger vertical dimensions, or small bridges instead of culverts, will allow more ice to form before they are blocked. This may easily result in openings that are larger than those required to carry the design storm or the design flood. Providing more drainage facilities than otherwise might be required is based on the idea that ice blockages will divert flow to spots that are normally expected to be dry. Thus the route or installation would be protected from unexpected washouts.

Another design solution is the use of staggered culverts. This means that two or more culverts are used for one stream, one at the ordinary location at the base of the fill, and another at a higher elevation in the fill (Figure 9). The higher culvert is usually dry except during the spring, when it carries runoff while the lower culvert is blocked by ice. The lower culvert will eventually be cleared of ice as the thaw progresses, leaving the higher culvert dry again. This technique works only where the fill is deep enough to handle the higher pipe, and where there is enough room to store the ice that will form upstream when the lower culvert is blocked.

Some ice problems in ditches and small streams can be solved by modifying the channel. This generally means deepening and straightening the channel, and perhaps even making a very narrow and deep channel for low winter discharges (Figure 10). Deepening the channel is usually done at riffles or rapids, because ice blockages often get started at these shallow areas. Deepened channels allow an ordinary ice cover to form, and yet provide adequate space beneath the ice cover to carry the flow.

ADDITIONAL INFORMATION

Four CRREL publications that may prove useful as sources of additional information are listed below. These reports apply to the more severe problems of icing in very cold climates, but the ideas they contain are at least partly applicable to the more general problems of ice-blocked drainage facilities.

Carey, K.L. (1970) Icing occurrence, control and prevention: An annotated bibliography. USACRREL Special Report 151. AD 711534.

Carey, K.L. (1973) Icings developed from surface water and ground water. USACRREL Cold Regions Science and Engineering Monograph III-D3. AD 765452.

Carey, K.L., R.W. Huck, and D.A. Gaskin (1975) Prevention and control of culvert icing: Summary report on studies, FY 1966-70. USACRREL Special Report 224. AD A010328.

Gaskin, D.A., and L.E. Stanley (1974) Application of electrical energy to culvert icing problems: A laboratory study. USACRREL Technical Report 248, AD 777516.

FIGURES 1-10



Figure 2. Ice formed in the bottom of a ditch in late fall. The ice level will rise as flow and freezing continue.



Figure 1. An ice-filled culvert being cleared by steam and hand tools to prepare for spring runoff.

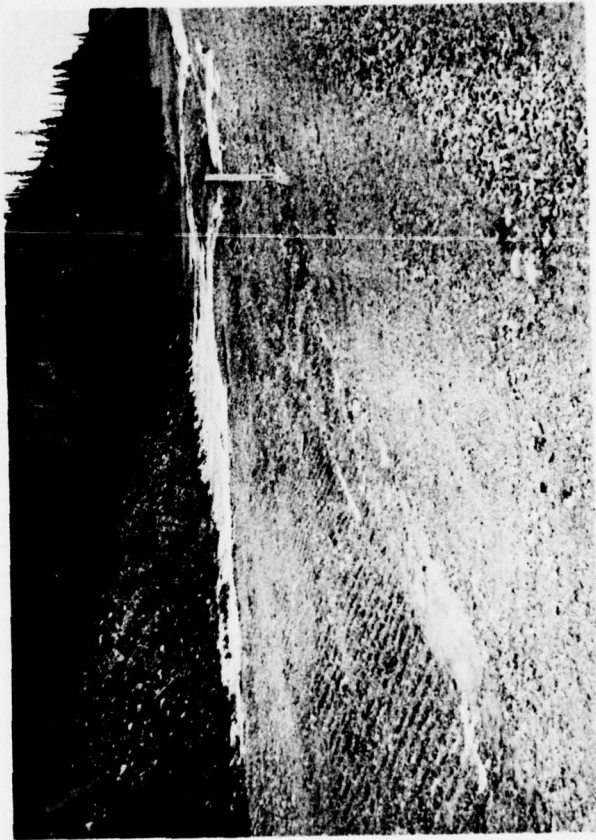


Figure 3. Seepage from the backslope has frozen and begun to fill this wide ditch with ice.

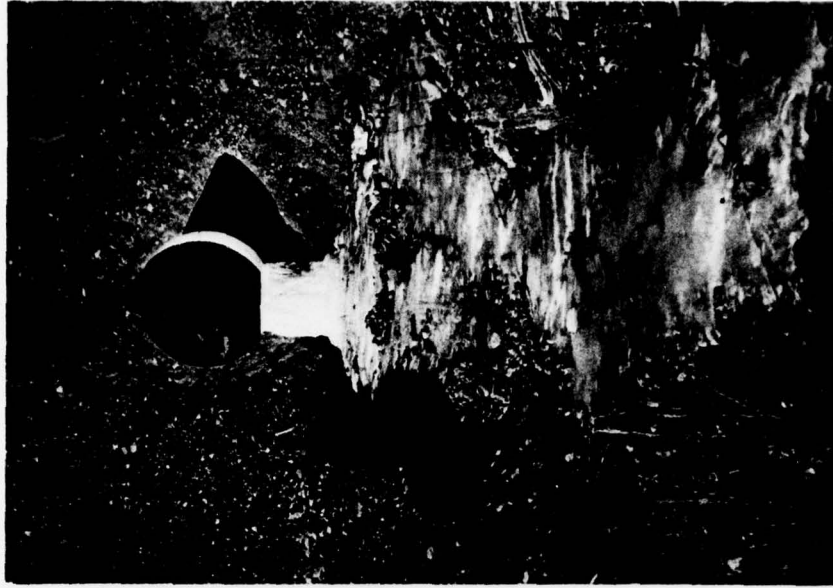
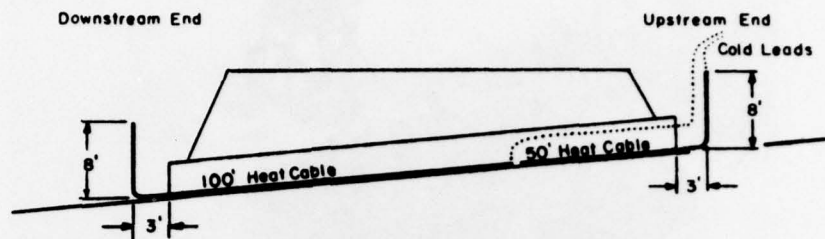


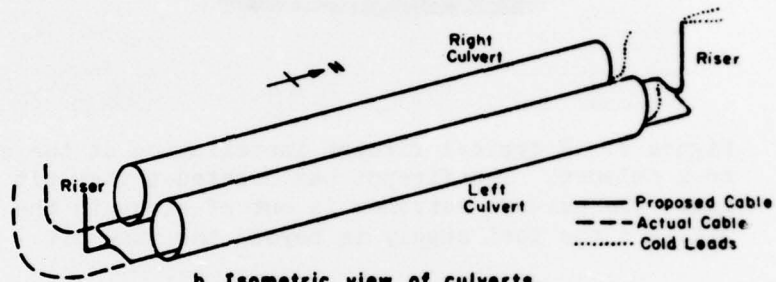
Figure 4. Free-fall culvert outlet in the early stages of ice formation. Continued flow and freezing will block it.



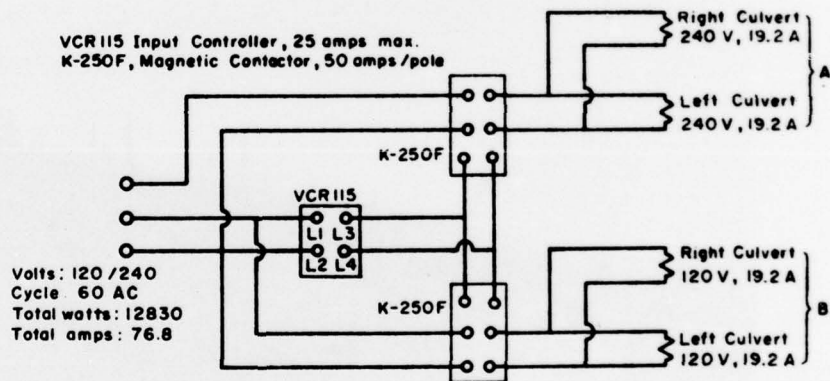
Figure 5. Water seepage down the face of this cut slope in rock has frozen and completely filled the ditch between the cut face and the road.



a. Culvert profile showing cable installation.



b. Isometric view of culverts.



A 2 ea 100 ft MIE Cable (SS19EB2) with 120 ft Cold Lead (R14/2C)
 B 2 ea 50 ft MIE Cable (SS19EB2) with 70 ft Cold Lead (R14/2C)

c. Wiring diagram.

Figure 6. Diagram of a typical electric heating cable installation.



Figure 7. A typical firepot installation at the entrance to a culvert. The firepot has created a thaw pit in the ice. The culvert entrance is out of sight in the thaw pit, and the fuel supply is beyond the thaw pit.



Figure 8. An ice fence installation, which is holding back ice formed by seepage from the slope at right.



Figure 9. A staggered culvert installation. The upper culvert at right can carry flow when the lower culvert is blocked by ice.



Figure 10. A specially-constructed narrow deep channel to carry low winter flows. The narrow channel is formed by rock-filled wire gabions.